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Effects of artificial acid rain on the microarthropod fauna in decomposing birch leaves

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With 2 figures

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Contents

1. Introduction

The two microarthropod groups Acari and Collembola are very abundant in most forest soils. There is increasing interest in their ecology and function, and also in their reactions to various human activities.

During recent decades, a marked increase in the acidity of rain and snow has been recorded over large parts of Europe. This is caused by industrial air pollutants, which may be spread by wind over long distances. The acidified precipitation in Scandinavia is mainly due to industrial outlets in middle Europe (DOVLAND et al. 1976; OECD 1977). The same kind of problem exist in North America (LIKENS et al. 1979).

The Norwegian "SNSF-project" has dealt with the effects of acid precipitation on forests and on fish. Within this project, reactions among microarthropods to changes in soil acidity have been studied. HÅGVAR & ABRAHAMSEN (1980) allowed soil animals to colonise sterilized soil samples which had been adjusted to three different pH levels. Different soil pH influenced the success of colonising by a number of species of Acari, Collembola and Enchytraeidae. Within all three groups, "preferences" both for low and high pH values were found. A number of these observations have been supported by field studies, in which experimental plots in coniferous forest were limed or treated with artificial acid rain of different pH values (HÅGVAR & ABRAHAMSEN 1977a, b; HÅGVAR 1978; HÅGVAR & AMUNDSEN 1981).

The present experiment adds a new substrate to these studies, namely deciduous leaves. Effects of artificial acid rain on the microarthropod fauna in decomposing birch leaves were studied both in the field and in a more controlled greenhouse experiment. The effects of acidification on decomposition rate and leaf chemistry have already been published (HÅGVAR & KJØNDAL 1981a). Succession of the microarthropod fauna in decomposing birch leaves has also been clarified (HÅGVAR & KJØNDAL 1981b).

Most of the Oribatei material from the present study was included in a thesis at the University of Oslo (KJØNDAL 1980). The rest of the microarthropod material and the writing has been the responsibility of the first author.

2. Material and methods

Detailed information on the field site and the experimental design in the field and greenhouse studies have been presented by HÅGVAR & KJØNDAL (1981a). Only the main points shall be given here.

In the field study, birch leaves (mixture of *Betula verrucosa* EHRH. and *B. pubescens* EHRH. in a ratio of 1 : 2) were kept in cylindrical litter bags (3 cm high and 6.5 cm in diam., with 1 mm mesh size). The bags were inserted into the 0 layer (0—3 cm), so that the upper surface was at the same level as the litter surface. Study plots, measuring 4 × 4 m and containing small *B. verrucosa* plants (0.5—1 m), were used. They were situated on a clear-cut area in a Norway spruce/Scots pine forest near Oslo, with a podzol soil (Typic Udipsamment). The experiment was designed with for replications. Treatments included unwatered plots and plots which during the frost-free period (May to September) were supplied with 50 mm artificial "rain" monthly of the following *p*H values: 6, 4, 3 and 2. The "rain" was produced from ground water by adding controlled amounts of sulphuric acid.

Litter bags were laid out on 28. 7. 1975 and sampled on the following dates: 19. 9. 1975, 28. 4. 1976, 2.—9. 11. 1976 and 10. 11. 1978. No effects were found due to the watering alone (*p*H 6). Significant reactions among microarthropods to increased acidification were recorded only at the last sampling. A total of 76 litter bags were extracted from this sampling: 20 from *p*H 6-treated plots, 19 from each of *p*H 4- and *p*H 3-treated plots, and 18 from *p*H 2-treated plots. Due to the very time-consuming work of counting, only adult Oribatei among the mites were counted from *p*H 4-treated bags. The chances of finding effects of acidification were also judged to be very small in this treatment. The counting of Mesostigmata was limited to 16 bags from each of the *p*H 6- and the *p*H 2-treatments.

The greenhouse study was performed with the same kind of litter, kept in smaller cylindrical litter bags (3 cm high and 3.4 cm in diam.), which were correspondingly inserted into the 0 layer of a forest soil similar to that in the field experiment. Besides "fresh" litter, also "old" litter having lost 40 % of the dry weight, and already containing a rich microarthropod fauna, was used. The intention was to study the effect of acidification both during the early phase when animals colonised the litter, and at a more advanced state of decay. Both categories of litter were watered twice weekly with 10 mm "rain" of the following *p*H values: 5.3, 3 and 2. In "fresh" litter, *p*H 4 was also included. The salt content was adjusted to that of natural rain.

The number of litter bags within each treatment was 15 for "fresh" litter and 12 for "old" litter. The forest soil in question was kept in drained plastic containers. This experiment had some advantages compared to the field experiment: natural rain was excluded, the artificial rain was given more frequently, and it was also applied more evenly on the bags. The greenhouse experiment was run for three months (November 1977 to February 1978).

Extraction was performed according to MACFADYEN (1961). To allow the animals to migrate through the sample, the leaves were packed vertically.

Statistical calculations were based on the analysis of variance with estimation of a "least significant difference". In the present case, where a high number of species have been tested at 5 % significance level, one should bear in mind that one in twenty "effects" is not reliable.

3. Results

3.1. Field experiment

At the fourth sampling, significant effects of acidification were recorded among Oribatei, Mesostigmata and Collembola (Table 1). Except for a few cases, these effects were limited to the strongest treatment (*p*H 2). However, the many cases of clear trends in the material indicate that application of *p*H 3-water also affected the fauna.

The mean abundance of Oribatei increased three-fold on the most acidified plots. This was mainly due to an increase in Brachychthoniidae and *Tectocepheus velatus* respectively to about seven and eleven times the control value. *Brachychochthonius zelawaiensis* alone increased its mean abundance about forty times. The total abundance of other main groups was not significantly changed. Most reactions represented an increase, but two Collembola species were reduced in abundance: *Isotoma notabilis* and *Lepidocyrtus cyaneus*.

Table 1 also contains some non-significant tendencies which will be further commented upon in the Discussion. The total number of microarthropods per bag increased non-significantly in acidified samples.

In Fig. 1, the composition of the whole microarthropod fauna in control-watered and the most acidified plots have been compared. Acidification increased the dominance of Oribatei and reduced the percentage of Collembola.

Table 1. Effect artificial acid rain (diluted sulphuric acid) on the microarthropod fauna in decomposing birch leaves (field experiment)

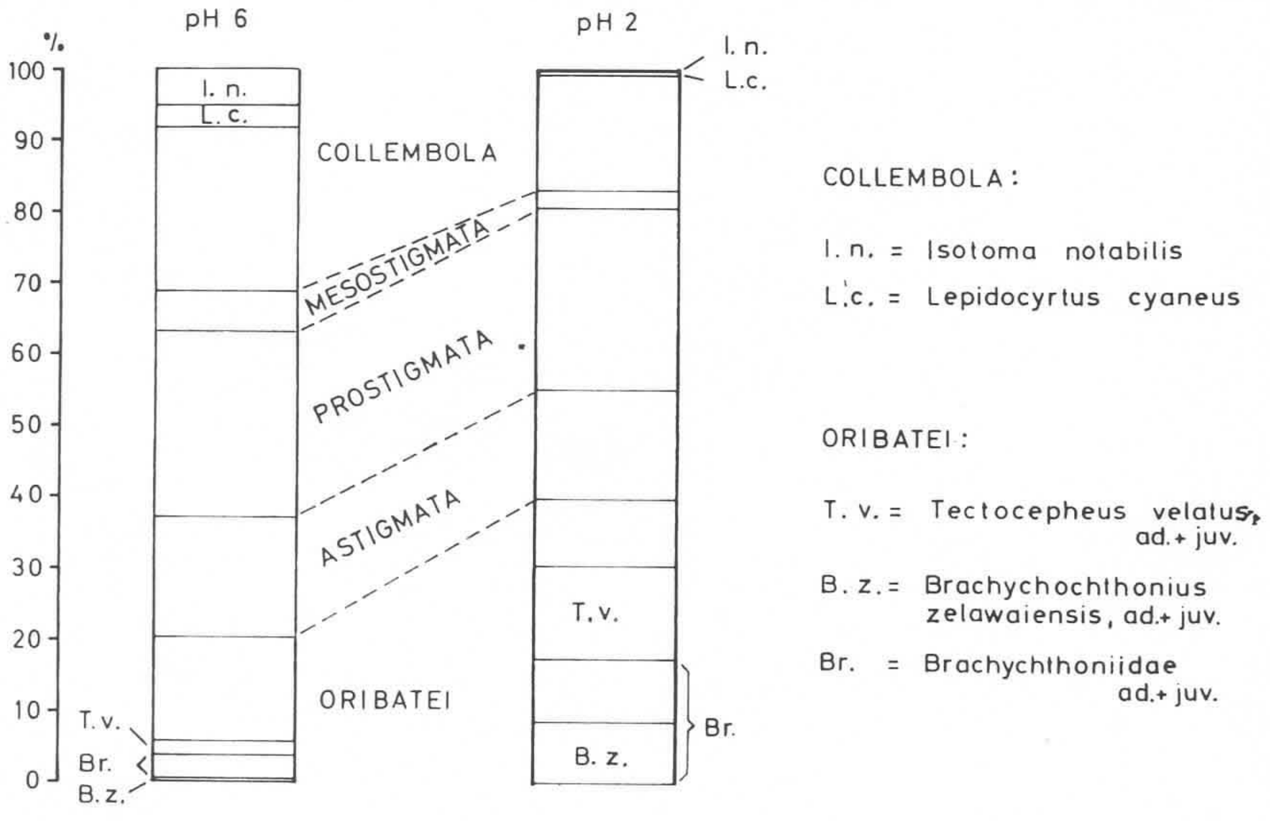
*p*H in artificial rain	*p*H 6 (ground water)	*p*H 4	*p*H 3	*p*H 2	Significance (related to *p*H)
Oribatei					
Brachychochthonius zelawaiensis (SELLN.), ad. + juv.	2.0 ± 2.9	N.c.	10.7 ± 8.3	83.8 ± 53.6	6 & 3 < 2**
Other Brachychthoniidae, ad. + juv.	20.5 ± 9.3	N.c.	57.0 ± 13.2	84.5 ± 49.5	6 < 2*
Brachychthoniidae, **total**	22.5 ± 11.7	N.c.	67.7 ± 18.6	168.3 ± 102.5	3 < 2* 6 < 2**
Tectocepheus velatus (MICH.), ad. + juv.	11.4 ± 12.5	18.8 ± 10.6	33.2 ± 49.3	125.8 ± 72.9	3 < 2* 4 & 6 < 2**
Nothrus silvestris NICOLET, ad. + juv.	1.1 ± 1.1	1.4 ± 1.4	3.1 ± 4.2	3.5 ± 3.2	
Oppia obsoleta (PAOLI), ad.	4.2 ± 3.3	3.7 ± 1.9	6.6 ± 6.5	12.3 ± 7.7	
O. nova (OUDMS.), ad.	0.1 ± 0.1	1.2 ± 1.2	1.8 ± 2.8	3.2 ± 3.2	
Oribatei except Brachychthoniidae, ad.	66.7 ± 32.5	65.8 ± 8.7	94.2 ± 33.4	93.1 ± 37.4	
Oribatei except Brachychthoniidae, ad. + juv.	106.7 ± 44.6	N.c.	157.7 ± 40.5	220.9 ± 63.9	6 < 2*
Oribatei, **total**	129.2 ± 34.9	N.c.	225.3 ± 58.1	389.1 ± 151.1	3 < 2* 6 < 2**
Mesostigmata					
Leioseius bicolor (BERLESE), ad.	0.1 ± 0.1	N.c.	N.c.	1.9 ± 1.0	6 < 2**
Mesostigmata, **total**	36.7 ± 11.1	N.c.	N.c.	22.4 ± 15.5	
Prostigmata					
Prostigmata, **total**	167.3 ± 71.5	N.c.	201.9 ± 139.7	250.1 ± 165.2	
Astigmata					
Astigmata, **total**	105.6 ± 127.5	N.c.	145.1 ± 91.3	150.2 ± 120.4	
Acari, **total**	438.8 ± 194.8	N.c.	N.c.	811.8 ± 414.7	
Collembola					
Isotoma notabilis SCHÄFFER, ad. + juv.	33.0 ± 11.4	23.0 ± 9.3	11.0 ± 7.4	2.3 ± 3.3	2 < 4** 2 < 6*** 3 < 6**
Lepidocyrtus cyaneus TULLBERG, ad. + juv.	18.3 ± 12.3	5.5 ± 2.2	6.9 ± 2.6	4.5 ± 2.5	2, 3 & 4 < 6*
Neanura muscorum (TEMPLETON), ad. + juv.	1.3 ± 1.0	1.6 ± 1.3	2.1 ± 0.9	4.2 ± 2.1	6 & 4 < 2*
Friesea mirabilis TULLBERG, ad. + juv.	9.9 ± 5.5	7.9 ± 1.8	6.2 ± 2.5	3.3 ± 1.4	
Mesaphorura yosii RUSEK, ad. + juv.	0.8 ± 0.7	0.8 ± 1.2	1.5 ± 0.8	5.7 ± 8.6	
Collembola, **total**	200.9 ± 19.2	171.1 ± 66.3	152.7 ± 35.9	168.0 ± 137.9	
Microarthropoda, **total**	639.7 ± 191.3	N.c.	N.c.	979.8 ± 549.8	

Mean values per litter bag and standard deviation based on four replications are given after more than three years (sampling IV). Significant effects are listed, together with some interesting tendencies. Significance levels: * = P ⩽ 0.05, ** = P ⩽ 0.01, and *** = P ⩽ 0.001. N.c. = Not counted.

Table 2. Effect of artificial acid rain (diluted sulphuric acid) on Collembola associated with birch

Stage of decomposition *p*H in artificial rain	Early phase			
	*p*H 5.3 (Distilled water)	*p*H 4	*p*H 3	*p*H 2
Willemia anophthalma BÖRNER		0.1 ± 0.3		0.5 ± 1.1
Friesea mirabilis (TULLBERG)	0.8 ± 0.8	0.6 ± 0.8	0.8 ± 0.9	0.4 ± 0.8
Anurida pygmaea (BÖRNER)	0.2 ± 0.8	0.2 ± 0.4		0.2 ± 0.6
A. forsslundi (GISIN)	0.6 ± 1.4		0.3 ± 0.9	0.1 ± 0.4
Neanura muscorum (TEMPLETON)		0.3 ± 0.6	0.1 ± 0.3	
Onychiurus absoloni (BÖRNER)	0.5 ± 0.8	0.1 ± 0.3	0.1 ± 0.4	
O. armatus (TULLBERG) s.l.	22.8 ± 12.2	29.0 ± 15.0	24.7 ± 12.4	3.4 ± 3.2
Mesaphorura yosii RUSEK	0.3 ± 1.1	0.1 ± 0.3	0.1 ± 0.3	0.3 ± 0.6
M. tenuisensillata RUSEK	0.1 ± 0.3			0.1 ± 0.3
Anurophorus binoculatus (KSENEMAN)				
Folsomia sensibilis (KSENEMAN)			0.1 ± 0.3	
Isotomiella minor SCHÄFFER	5.1 ± 3.5	2.7 ± 2.5	6.9 ± 4.4	0.4 ± 0.6
Isotoma notabilis SCHÄFFER	20.1 ± 13.3	18.3 ± 12.0	28.3 ± 16.1	8.9 ± 5.0
Lepidocyrtus cyaneus TULLBERG	0.5 ± 0.6		0.4 ± 0.8	
Neelus minimus WILLEM	8.9 ± 7.5	3.1 ± 3.7	8.2 ± 9.6	0.3 ± 0.8
Other Sminthuridae (mainly juv.)	0.9 ± 1.0	2.1 ± 2.5	1.3 ± 1.2	0.1 ± 0.4
Collembola, **total**	60.9 ± 18.9	56.7 ± 20.8	71.3 ± 22.8	14.7 ± 4.4
Number of species	12	11	12	11

Mean numbers (ad. + juv.) per litter bag ± SD, and significant differences between treatments, cies is indicated at the bottom.



leaves in early or late decomposition phases (greenhouse experiment)

Significance (related to *p*H)	Late phase *p*H 5.3 (Distilled water)	*p*H 3	*p*H 2	Significance (related to *p*H)
			0.2 ± 0.6	
	0.8 ± 1.2	0.4 ± 0.9		
	0.3 ± 0.5			
	0.1 ± 0.3			
	2.4 ± 4.7	2.3 ± 3.1	0.4 ± 0.7	
2 < 3, 4 & 5***	1.9 ± 0.8	3.5 ± 4.7	1.4 ± 1.9	
		0.2 ± 0.4	0.3 ± 0.5	
	0.1 ± 0.3	0.2 ± 0.4	0.2 ± 0.4	
	0.2 ± 0.4	0.2 ± 0.4		
2 < 3 & 5***	2.7 ± 3.0	2.4 ± 1.9	0.1 ± 0.3	2 < 3 & 5**
2 < 4 and 4 < 5*				
4 < 3***				
2 < 3***	4.2 ± 3.9	1.3 ± 1.6	0.3 ± 0.7	2 < 5***
2 < 4 & 5*				3 < 5**
4 < 3*				
	1.0 ± 1.1			2 & 3 < 5***
2 < 5***	25.3 ± 23.1	11.7 ± 7.6	16.8 ± 12.7	
2 < 3**				
4 < 3 & 5*				
2 < 4***	6.1 ± 4.7	4.7 ± 3.9	1.2 ± 1.4	2 < 5**
2 < 3*				2 < 3*
5 < 4*				
2 < 3, 4 & 5***	45.1 ± 25.6	26.8 ± 12.1	20.8 ± 13.1	2 < 5**
4 < 3*				3 < 5*
(Total 15)	12	10	9	**(Total 14)**

are given. Significance levels: * = $P \leqslant 0.05$, ** = $P \leqslant 0.01$, *** = $P \leqslant 0.001$. Number of spe-

3.2. Greenhouse experiment

As seen from Tables 2—4, a large number of species and groups among Microarthropoda were influenced by acidification in the greenhouse experiment. Application of "rain" with *p*H 2 strongly reduced the total abundance of Collembola, both in "early" and "late" phases (Table 2). In the "late" phase, the reduction was significant also at the *p*H 3-treatment. All reactions observed in single species, regardless of decomposition phase, were reductions in abundance. In the "late" phase, acidification seemed to reduce species numbers somewhat.

The total abundance of Oribatei was not significantly influenced by acidification (Table 3). Among single species or restricted groups, most reactions were reductions. However, in both "early" and "late" phases, the abundance of *Steganacarus* spp. and *Tectocepheus velatus* increased significantly in the most acidified bags. The same was found for *Oppia nova* in "late" phase. Species numbers did not seem to be influenced.

Reactions among Mesostigmata appeared to be different in "early" and "late" decomposition phases (Table 4). While all significant reactions in the "late" phase, both among single species and in total numbers, were reductions, there was a general tendency for a peak at the two medium treatments (*p*H 4 and *p*H 3) in the "early" phase. *Eviphis ostrinus*, however, seemed to increase in abundance by acidification in the "early" phase. Species numbers were practically unaffected by treatments.

Fig. 1. Composition of the microarthropod fauna in birch litter bags treated with ground water of *p*H 6, and with artificial "rain" of *p*H 2.
Data from field experiment.

Table 3. Effect of artificial acid rain (diluted sulphuric acid) on Oribatei associated with birch

Stage of decomposition	Early phase			
*p*H in artificial rain	*p*H 5.3 (Distilled water)	*p*H 4	*p*H 3	*p*H 2
Steganacarus spp., ad.	8.5 ± 4.3	9.8 ± 3.9	11.8 ± 6.1	22.8 ± 13.3
Phthiracarus spp., ad.				0.07 ± 0.26
Euphthiracaridae, ad.	0.07 ± 0.26	0.07 ± 0.26	0.13 ± 0.35	
Brachychochthonius zelawaiensis (SELLN.), ad. + juv.	2.2 ± 1.9	0.13 ± 0.35	0.36 ± 0.50	0.87 ± 1.2
Other Brachychthoniidae, ad. + juv.	28.1 ± 10.2	21.5 ± 10.5	12.8 ± 7.4	9.1 ± 6.6
Brachychthoniidae, ad. + juv.	30·3 ± 11.2	21.7 ± 10.6	13.1 ± 7.4	10.0 ± 7.3
Nothrus silvestris NICOLET, ad. + juv.	1.6 ± 1.7	0.80 ± 1.1	2.4 ± 3.4	2.2 ± 2.1
Paulonothrus longisetosus (WILLM.), ad. + juv.	0.60 ± 0.83	0.60 ± 0.83	0.73 ± 1.1	0.53 ± 0.64
Platynothrus peltifer (C.L.K.), ad. + juv.	0.33 ± 0.62	0.07 ± 0.26	0.60 ± 0.63	0.07 ± 0.26
Camisia spinifer (C.L.K.), juv.			0.07 ± 0.26	
Nanhermannia sp., ad.	0.13 ± 0.35	0.07 ± 0.26		0.07 ± 0.26
Porobelba spinosa (SELLN.), ad. ± juv.	1.9 ± 3.4	1.5 ± 2.6	0.93 ± 1.5	0.80 ± 1.5
Carabodes femoralis (NIC.), ad.	0.07 ± 0.26			0.07 ± 0.26
C. labyrinthicus (MICH.), ad.	0.07 ± 0.26	0.07 ± 0.26	0.07 ± 0.26	0.07 ± 0.26
Tectocepheus velatus (MICH.), ad. + juv.	3.8 ± 2.5	1.9 ± 1.6	3.4 ± 4.1	13.4 ± 11.0
Adoristes poppei (OUDMS.), ad.	1.9 ± 2.0	1.4 ± 1.6	1.4 ± 1.4	1.7 ± 1.4
Oppia obsoleta (PAOLI), ad.	35.9 ± 19.1	42.4 ± 14.9	29.9 ± 13.7	30.0 ± 18.4
O. nova (OUDMS.), ad.	8.3 ± 12.1	0.53 ± 0.74	3.1 ± 2.3	0.27 ± 0.59
O. ornata (OUDMS.), ad.	3.5 ± 4.0	5.6 ± 5.9	1.9 ± 2.8	4.3 ± 3.4
Suctobelba spp., ad.	4.6 ± 4.3	6.0 ± 6.4	2.1 ± 3.5	3.1 ± 2.7
Hemileius initiales BERL., ad.	1.3 ± 1.6	0.13 ± 0.52	0.33 ± 0.72	0.33 ± 1.3
Eupelops duplex (BERL.), ad. + juv.	0.07 ± 0.26	0.27 ± 0.59	0.07 ± 0.26	
Ceratozetes gracilis (MICH.), ad.			0.07 ± 0.26	
Chamobates sp.	1.3 ± 1.5	1.3 ± 1.2	1.0 ± 1.6	
Oribatei juv., indet.	2.7 ± 2.0	2.6 ± 2.9	1.2 ± 1.5	2.4 ± 1.8
Oribatei, **total**	106.5 ± 33.0	97.3 ± 22.7	75.9 ± 28.3	92.3 ± 24.7
Number of species (minimum)	20	19	20	18

Mean numbers per litter bag ± SD, and significant differences between treatments, are given. at the bottom.

leaves in early or late decomposition phases (greenhouse experiment)

Significance (related to *p*H)	Late phase *p*H 5.3 (Distilled water)	*p*H 3	*p*H 2	Significance (related to *p*H)
3, 4 & 5 < 2***	4.4 ± 3.5	7.8 ± 6.0	12.3 ± 8.0	5 < 2**
			0.08 ± 0.29	
			0.08 ± 0.29	
2 < 5**	2.4 ± 3.7	2.1 ± 2.8	4.8 ± 3.6	
3 & 4 < 5***				
2 < 4 & 5***	17.9 ± 11.4	26.5 ± 22.1	11.0 ± 9.3	
3 < 4** & 5***				
4 < 5*				
2 < 4** & 5***	20.3 ± 13.1	28.5 ± 24.4	15.8 ± 11.4	
3 < 4* & 5***				
4 < 5*				
	0.33 ± 0.49	0.50 ± 0.90	1.2 ± 1.1	
	0.08 ± 0.29	0.50 ± 1.0	1.3 ± 1.4	
	0.25 ± 0.45	0.08 ± 0.29	0.17 ± 0.39	
		0.08 ± 0.29		
	1.6 ± 1.5	0.08 ± 0.29	0.33 ± 0.65	2 < 5**
				3 < 5***
	0.17 ± 0.39		0.25 ± 0.62	
3, 4 & 5 < 2***	3.1 ± 1.9	2.0 ± 2.9	6.4 ± 4.6	5 < 2*
				3 < 2**
	0.25 ± 0.45	0.42 ± 0.67	0.42 ± 0.51	
	5.1 ± 5.6	4.3 ± 3.5	3.4 ± 3.8	
2 < 5***	1.0 ± 1.2	0.67 ± 0.98	2.7 ± 2.5	5 < 2*
3 < 5*				3 < 2**
4 < 5**				
	9.5 ± 11.4	8.8 ± 9.4	14.0 ± 36.5	
	6.7 ± 4.7	4.7 ± 6.0	3.0 ± 2.1	
2 & 3 < 5*	0.42 ± 0.79			
4 < 5**				
	0.50 ± 0.52	0.25 ± 0.45	0.08 ± 0.29	
		0.08 ± 0.29		
2 < 3*	1.1 ± 0.90	1.3 ± 1.1	1.7 ± 1.9	
2 < 4 & 5**				
	4.3 ± 7.0	2.8 ± 4.1	1.3 ± 1.7	
	59.0 ± 27.7	61.8 ± 36.2	65.0 ± 57.6	
(Total 23)	17	17	18	**(Total 21)**

Significance levels: * = P ⩽ 0.05, ** = P ⩽ 0.01, *** = P ⩽ 0.001. Number of species is indicated

Table 4. Effect of artificial acid rain (diluted sulphuric acid) on Mesostigmata, Astigmata, Prostigsition phases (greenhouse experiment).

Stage of decomposition	Early phase			
*p*H in artificial rain	*p*H 5.3 (Distilled water)	*p*H 4	*p*H 3	*p*H 2
Mesostigmata				
Trachytes spp., ad. + large juv.	6.9 ± 3.8	2.1 ± 1.6	3.7 ± 3.1	2.9 ± 2.2
Other Uropodina, ad. + juv.	13.5 ± 6.3	11.5 ± 7.3	18.5 ± 8.1	15.9 ± 9.4
Uropodina, total	20.5 ± 7.3	13.6 ± 7.6	22.1 ± 9.4	18.8 ± 9.6
Prozercon kochi SELLNICK, ad. + large juv.	1.5 ± 1.7	2.7 ± 3.0	1.2 ± 1.4	1.1 ± 2.1
Parazercon sarekensis WILLMANN, ad. + large juv.		0.27 ± 0.59	0.20 ± 0.41	
Zerconidae, small juv.	0.47 ± 0.64	1.1 ± 1.5	0.40 ± 0.74	1.6 ± 2.5
Zerconidae, **total**	1.9 ± 1.8	4.0 ± 4.6	1.8 ± 1.8	2.7 ± 4.5
Eviphis ostrinus (KOCH), ad. + juv.	1.3 ± 1.7	2.1 ± 2.0	3.1 ± 1.8	3.0 ± 1.9
Pergamasus robustus OUDEMANS, ad.	1.3 ± 1.4	1.8 ± 1.5	2.3 ± 1.7	0.33 ± 0.49
P. cf. *lapponicus* TRÄGHÅRDH, ad.	0.60 ± 0.63	1.7 ± 1.5	0.87 ± 0.83	0.20 ± 0.41
P. sp., ad.	0.93 ± 0.80	1.6 ± 1.5	2.9 ± 1.8	0.73 ± 1.2
Veigaia nemorensis (C. L. KOCH), ad. + juv.	2.5 ± 2.3	2.5 ± 2.0	1.9 ± 1.7	3.1 ± 1.6
V. cerva (KRAMER), ad.	0.13 ± 0.35		0.47 ± 0.52	0.27 ± 0.59
Gamasina indet, ad.	0.13 ± 0.35	0.60 ± 0.63	0.13 ± 0.35	0.47 ± 1.2
Gamasina indet, juv. (mainly *Pergamasus*)	7.3 ± 3.3	16.1 ± 5.0	16.9 ± 5.0	8.4 ± 3.9
Gamasina except Zerconidae	14.1 ± 4.6	26.3 ± 7.4	28.7 ± 5.6	16.5 ± 4.5
Gamasina, **total**	16.0 ± 5.0	30.3 ± 8.2	30.5 ± 6.8	19.3 ± 7.6
Mesostigmata, **total**	36.5 ± 7.0	43.9 ± 13.0	52.6 ± 12.6	38.1 ± 13.4
Mesostigmata, number of species (minimum)	10	10	11	10
Astigmata				
Schwiebea cf. *nova* VITZTHUM, ad. + juv.	82.4 (Est.)	N.c.	N.c.	205.8 (Est.)
S. cf. *cavernicola* (OUDEMANS), ad. + juv.	43.2 (Est.)	N.c.	N.c.	66.1 (Est.)
Tyrophagus sp., ad. + juv.	1.9 ± 4.3	0.40 ± 0.63	1.1 ± 2.6	
Astigmata, **total**	127.5 ± 135.3	30.4 ± 46.9	69.6 ± 57.9	271.9 ± 238.4
Prostigmata				
Prostigmata, **total**	39.6 ± 18.1	46.0 ± 29.4	28.0 ± 7.8	45.8 ± 18.2
Total Acari	310.0 ± 142.0	217.5 ± 65.7	226.1 ± 72.5	448.1 ± 243.9
Total Microarthropoda	370.9 ± 140.4	274.2 ± 63.9	297.4 ± 91.5	462.8 ± 242.9

Mean numbers per litter bag ± SD, and significant differences between treatments, are given. Mesostigmata is indicated. N.c. = Not counted. Est. = Estimated.

mata, total Acari and total Microarthropoda associated with birch leaves in early or late decompo-

	Late phase			
Significance (related to pH)	pH 5.3 (Distilled water)	pH 3	pH 2	Significance (related to pH)
2 & 4 < 5*** 3 < 5**	2.5 ± 2.7	1.5 ± 1.7	1.1 ± 1.9	
	4.3 ± 5.3	1.5 ± 2.3	1.9 ± 3.4	
4 < 3** 4 < 5*	6.8 ± 7.6	3.0 ± 3.2	3.0 ± 5.2	
	1.9 ± 1.4	1.1 ± 1.6	0.17 ± 0.39	2 < 5**
	0.08 ± 0.29	0.17 ± 0.39	0.08 ± 0.29	
	0.92 ± 1.4	0.67 ± 0.98	0.25 ± 0.45	
	2.9 ± 2.2	1.9 ± 2.5	0.50 ± 0.67	2 < 5**
5 < 3** 5 < 2*	0.67 ± 1.2	0.42 ± 0.90	0.08 ± 0.29	
2 < 3*** 2 < 4** 5 < 3*	0.25 ± 0.45	0.17 ± 0.39	0.08 ± 0.29	
2 < 4*** 3 < 4* 5 < 4**	0.50 ± 0.80	0.17 ± 0.39	0.50 ± 1.2	
2 & 5 < 3*** 3**	0.08 ± 0.29	0.33 ± 0.65		
	2.7 ± 1.8	2.6 ± 2.6	0.58 ± 0.79	2 < 3 & 5*
	0.25 ± 0.45	0.17 ± 0.39		
	0.42 ± 0.67	0.08 ± 0.29	0.17 ± 0.58	
2 & 5 < 3 & 4***	2.5 ± 2.6	2.1 ± 1.6	1.6 ± 1.8	
2 & 5 < 3 & 4***	7.3 ± 5.5	6.0 ± 3.5	3.0 ± 3.4	2 < 5*
2 & 5 < 3 & 4***	10.3 ± 5.8	7.9 ± 4.7	3.5 ± 3.6	2 < 3* 2 < 5**
2 < 3** 4 < 3* 5 < 3***	17.0 ± 11.9	10.9 ± 6.7	6.5 ± 8.6	2 < 5**
	11	11	10	
Probably 5 < 2*	10.8 (Est.)	N.c.	36.4 (Est.)	
	3.7 (Est.)	N.c.	5.4 (Est.)	
	0.08 ± 0.29	0.58 ± 1.0		
3 < 2** 4 < 2*** 5 < 2* 4 < 5*	14.6 ± 24.0	6.1 ± 12.8	41.8 ± 51.2	3 < 2*
	14.3 ± 7.2	14.5 ± 9.6	14.8 ± 9.9	
3 & 4 < 2*** 5 < 2*	104.9 ± 51.1	93.3 ± 41.8	128.2 ± 123.4	
3 & 4 < 2**	150.0 ± 61.5	120.1 ± 48.9	149.0 ± 124.3	

Significance levels: * = $P \leqslant 0.05$, ** = $P \leqslant 0.01$, *** = $P \leqslant 0.001$. The number of species in

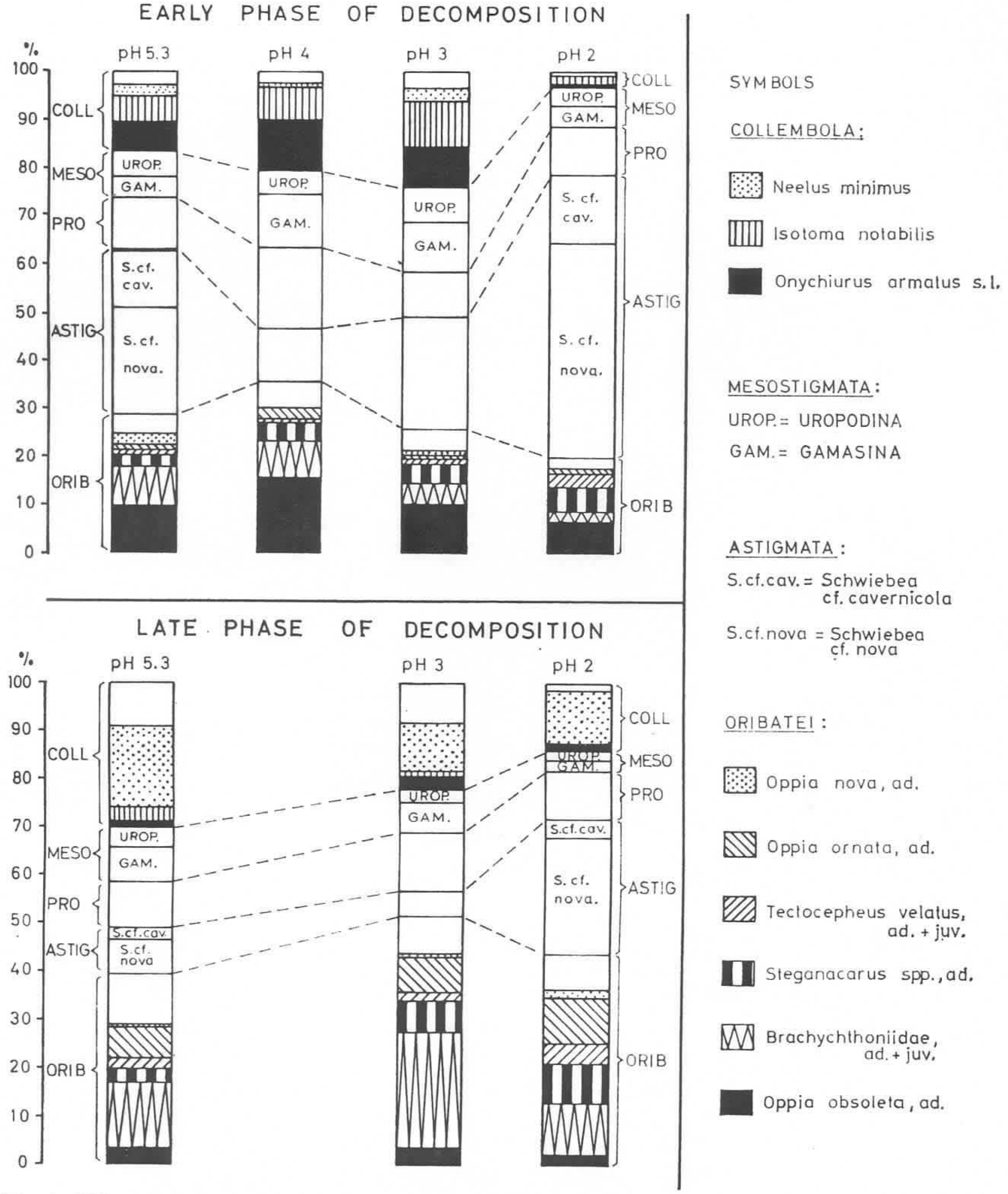


Fig. 2. Effect of acidification on the microarthropod fauna in birch leaves in "early" and "late" phases of decomposition (greenhouse experiment). The *p*H of artificial rain is indicated above the columns (*p*H 5.3 is distilled water).

The highest Astigmata numbers were found at the *p*H 2 treatment in both decomposition phases. This was due to the dominant species *Schwiebea* cf. *nova*. In the "early" phase, the high proportion of Astigmata gave a significant maximum in the most acidified bags for both total Acari and total Microarthropoda (Table 4).

The effect of increased acidification on the relative dominance within Microarthropoda is illustrated in Fig. 2 for both decomposition phases. The *p*H 2-watered bags were always characterized by a high proportion of Astigmata (mainly *Schwiebea* cf. *nova*) and a low percentage of Collembola. Increased dominance of *Steganacarus* spp. and *Tectocepheus velatus* was also common for both phases.

Comparing field and laboratory results, it is evident that the more frequent application of acidified water in the laboratory, even after a comparatively short time, created more profound and numerous effects than in the field study. Many reactions to the *p*H 2 water in the laboratory have the character of "shock-effects". However, it is interesting to find common features between the two experiments in the cases of increased abundance. *Tectocepheus velatus* increased significantly in both experiments. *Oppia nova* and Astigmata (mainly *Schwiebea* cf. *nova*), which increased significantly in the laboratory, showed clear trends of increase also in the field experiment (Table 1).

4. Discussion

Field litter bags received both a larger amount of acidified water than the greenhouse litter bags (850 versus 240 mm), and a larger dose at each watering (50 versus 10 mm). However, greenhouse litter bags received acid "rain" eight times monthly, while field litter bags were watered only once monthly, and only five times a year. The frequent acid "stress" with *p*H 2-water in greenhouse litter bags led to a general reduction in the microarthropod fauna, except for a few cases of increased abundance of certain species. The less frequent application of acid "rain" to the field litter bags also resulted in some reductions in abundance, but most of the reacting species showed increased abundance in acidified bags. Differences may also be due to the fact that natural precipitation would periodically wash out acid from the field bags.

Three weeks before the last field sampling, ordinary soil samples for extraction of microarthropods were taken on neighbouring experimental plots. The soil had received artificial "rain" of the following *p*H values: 6, 4, 3 and 2, and the mean soil *p*H in the O-layer (0—3 cm) was 3.93, 3.91, 3.75 and 3.40, respectively. Soil samples were even taken in limed plots with a mean soil *p*H of 6.24 in the O-layer. Reactions among Acari (Collembola not yet treated) to changes in soil *p*H were similar to those observed in the field litter bags (HÅGVAR & AMUNDSEN 1981). *Tectocepheus velatus* and total Oribatei (0—3 cm) showed increased abundance in the most acidified soil, and reduced abundance on limed plots. In *Brachychochthonius zelawaiensis*, there was a non-significant tendency for increased abundance in the most highly acidified soil, and a significant decrease in limed soil (0—3 cm). Total Brachychthoniidae (0—3 cm) and total Acari were also reduced in abundance after liming. *Nothrus silvestris*, which increased non-significantly in acidified birch leaves (Table 1), showed a tendency for increased abundance also in soil, and a significant reduction in limed plots (0—3 cm). Total Prostigmata and total Acari were, however, reduced in soil by the stronges acidification, while these groups increased non-significantly in litter bags given the same treatment. This difference is probably due to the longer period during which the soil had been acidified (from August 1972).

Further support for the observed reactions in field litter bags has been obtained from soil samples in two similar and neighbouring field experiments: application of artificial "rain" down to *p*H 2.5 in a young spruce *(Picea abies)* stand, and liming in a young lodgepole pine (*Pinus contorta* DOUGL.) stand (HÅGVAR 1978; HÅGVAR & AMUNDSEN 1981). Acidification gave increased abundance of "Brachychthoniidae other than *B. zelawaiensis*", total Brachychthoniidae (3—6 cm) total Oribatei (3—6 cm) and total Acari (4—6 cm). The Collembola species *Isotoma notabilis* was non-significantly reduced. Another Collembola, *Mesaphorura yosii*, which increased non-significantly in acidified bags (Table 1), increased very markedly in acidified soil. In limed soil, both *B. zelawaiensis* and *N. silvestris* were reduced. *Friesea mirabilis*, with a non-significant reduction in acidified litter bags, tended to increase in limed soil.

A laboratory experiment in which soil animals were allowed to colonise sterile soil samples with adjusted *p*H levels (HÅGVAR & ABRAHAMSEN 1980) also supports the conclusions from the field litter bags, and even confirms several of the non-significant trends included in Table 9. Among the microarthropods which preferred to colonise the most acid soil samples were *T. velatus*, *B. zelawaiensis*, *N. silvestris*, *Oppia nova*, *O. obsoleta*, *Schwiebea* cf.

nova, *M. yosii*, total Oribatei, total Acari and total Microarthropoda. Limed samples with a high soil pH were preferred by *I. notabilis* and *F. mirabilis*.

The few cases of increased abundance in the greenhouse experiment confirm this over-all picture, except for the clear response of *Steganacarus* sp. in both decomposition phases. Perhaps the intense acidification had reduced the content of polyphenols or in other ways made the leaves more palatable for these macrophytophages. The general reduction in microarthropods indicates drastic changes with time. Continued application of acid "rain" of pH 2 to the soil in which the greenhouse litter bags had been situated led to an almost complete extinction of the microarthropod fauna after two years of treatment. All vegetation died, and spruce needles kept in corresponding litter bags for one year were much less infested by fungi than in control soil treated with distilled water. As fungal hyphae play an important role in the diet of many microarthropods, a general reduction in the soil fungal biomass would be a reasonable explanation of microarthropod reduction in strongly acidified greenhouse litter bags.

In a Swedish field experiment, the soil of a Scots pine forest was treated with very high concentrations of sulphuric acid over six years (50 or 150 kg H_2SO_4 ha^{-1} $year^{-1}$, applied as 0.8 M; TAMM & WIKLANDER 1980). A reduction in the amount of FDA-active mycelium was observed in the raw humus, and a reduction both of FDA-active and total mycelium in the A_e layer (BÅÅTH et al. 1980). At the same time, *T. velatus* showed increased abundance in the A_e layer. Fungal analysis of the raw humus layer of the soil in which the present field litter bags had been situated did not reveal significant effects of acidification on fungal biomass, neither as FDA-active hyphae nor total hyphae (BÅÅTH et al. 1979). Obviously, the abundance of certain fungal-feeding species may increase even in situations where the fungal biomass is unchanged or reduced.

Neither the present work nor earlier acidification experiments indicates that reduced predation by Gamasina led to the observed increase of certain Collembola and Acari species. Changes in competition is another possible factor, but it is difficult to interpret and has not given fruitful suggestions in the present case. Literature data and unpublished results strongly indicate that in many species, there is a connection between reactions to acidification and the occurrence in natural soils of different pH. For instance, *T. velatus*, *N. silrestris*, *B. zelawaiensis*, *S.* cf. *nova* and *M. yosii* occur mainly in very acid habitats with a well-developed raw humus layer, while *I. notabilis* is most abundant in mull forest soils with higher pH (for review see HÅGVAR & ABRAHAMSEN 1980 and HÅGVAR & AMUNDSEN 1981). These two papers suggest that in several species, the reproduction success is related to soil pH. Among the "acidophile" species in the colonisation experiment (HÅGVAR & ABRAHAMSEN 1980), the percentage of juveniles was highest in the most acid soil. Also in the present experiment, the percentage of juveniles of *T. velatus* was highest in the most acidified field litter bags (80%), compared to bags given water of pH 6 (62%). Parallel effects were observed in both "early" and "late" decomposition phases in the greenhouse experiment.

In field litter bags, changes in microarthropod fauna were found only among those treatments which affected leaf chemistry (HÅGVAR & KJØNDAL 1981). Bags collected during the two first samplings had received artificial acid "rain" only twice, and effects on leaf chemistry were small. The third sampling was taken after seven waterings. Really large effects on leaf chemistry were not achieved until the last sampling, after seventeen waterings. When also taking into account the low number of replications (four), it is understandable that significant effects of acidification on microarthropods were not recorded until the end of the experiment.

5. Final remarks

It is difficult to say whether the observed effects of rather strong, artificial acidification can indicate long-term effects of acid rain and snow. We do not know, for instance, to what degree the effect of pH 2-water is due mainly to the strong concentration itself, or if the same amount of acid given in weaker concentrations over a much longer period would give similar results. Concerning soil chemistry, however, it is evident that increased acidity of the artificial "rain" will change the

equilibrium between the solid phase and water phase in soil (ABRAHAMSEN 1980). Neither do we know the mechanisms which regulate the observed faunal changes.

Two lines of investigation could clarify these problems: One would be to run experiments with weak acidification over a long time (10—20 years), and the other to reveal experimentally the factors which directly or indirectly have affected the animal populations.

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7. Summary . Résumé

Effects of artificial acid rain on the microarthropod fauna in decomposing birch leaves

In a field experiment, artificial "rain" of *p*H 6, 4, 3 and 2 was applied to birch leaf litter (mixture of *Betula pubescens* EHRH. and *B. verrucosa* EHRH.) kept in litter bags with 1 mm mesh size. Fifty mm artificial "rain" was given once monthly in the frost-free period of the year (May—September), and the experiment was extended over more than three years. The various *p*H values were achieved by adding sulphuric acid to ground water (*p*H 6). Because the habitat (a clear-cut area) was rather warm and dry during summer time, less than 40% dry weight was lost during the whole study period. At the end of the experiment, significant effects of acidification were found among Oribatei, Mesostigmata and Collembola. In the most strongly acidified bags, the abundance of Oribatei had increased significantly. This was mainly due to a marked increase in the numbers of Brachychthoniidae [mainly *Brachychochthonius zelawaiensis* (SELLN.)] and *Tectocepheus velatus* (MICH.). Increased abundance on plots given *p*H 2-water was also noted for *Leioseius bicolor* (BERL.) [Mesostigmata] and *Neanura muscorum* (TEMPLETON) [Collembola]. However, reduced abundance was recorded among two Collembola species: *Isotoma notabilis* SCHÄFFER and *Lepidocyrtus cyaneus* TULLBERG.

A similar experiment was run for three months in a greenhouse, using both leaves in an "early" decomposition phase, and leaves in a "late" phase. Watering was performed frequently, with 10 mm twice a week, and natural precipitation was excluded. The frequent application with *p*H 2-water over this comparatively short time strongly reduced the total abundance of Collembola in both decomposition phases. In the "late" phase, the reduction was significant also at the *p*H 3-treatment. All effects on single Collembola species were reductions. Several species of Mesostigmata seemed to achieve highest abundance at the *p*H 4- and *p*H 3-treatments in the "early" phase, while all reactions to acidification in the "late" phase were reductions (at the *p*H 2-level). Acidification did not affect the total abundance of Oribatei, but most reactions were reductions. However, in *Tectocepheus velatus* and *Steganacarus* spp., the abundance increased in both phases. Thus, the results revealed complicated reaction patterns, with great effect of the frequency of acid "rain" application. The field results are in accordance with other field studies and also a "preference" experiment, while the results from the greenhouse experiment have largely the character of "shock-effects".

Effets d'une simulation de pluies acides sur la faune des microarthropodes dans la litière de bouleau en décomposition

Lors d'un essai sur le terrain on a réalisé une simulation de «pluie» à *p*H 6, 4,3 et 2 sur de la litière de bouleau (mélange de *Betula pubescens* EHRH. et *B. verrucosa* EHRH.) maintenue dans des sacs de nylon à mailles de 1 mm. 50 mm de «pluie» simulée ont été appliqués une fois par mois durant la période de l'année sans gelée (mai—septembre) et l'expérience a été poursuivie durant trois ans. Les différentes valeurs de *p*H ont été obtenues par addition d'acide sulfurique en mélange avec de l'eau souterraine (*p*H 6). A peine 40% de la matière organique sèche ont été perdus pendant la période d'étude, principalement parce que l'habitat (surface déboisée) a été chaud et sec durant l'été. A la fin de l'expérience, on a mis en évidence des effets significatifs de l'acidification sur les Oribatei, les Mesostigmata et les Collembola. Dans les sacs les plus acidifiés l'abondance des Oribatei a augmenté significativement. Ceci tient principalement à une augmentation appréciable du nombre des Brachychthoniidae (principalement *Brachychochthonius zelawaiensis* (SELLN.) et *Tectocepheus velatus* (MICH.). Dans les endroits où de l'eau à *p*H 2 a été appliquée on a également observé une augmentation d'abondance de *Leioseius bicolor* (BERL.) (Mesostigmata) et *Neanura*

muscorum (TEMPLETON) (Collembola). Cependant, une réduction d'abondance a été enregistrée pour deux espèces de Collembole: *Isotoma notabilis* SCHÄFFER et *Lepidocyrtus cyaneus* TULLBERG.

Une expérience de même type a été entreprise durant trois mois en serre en utilisant deux types de feuilles: feuilles à un stade «moins avancé» de décomposition et feuilles à un stade «plus avancé» de décomposition. L'arrosage a été exécuté fréquemment, 10 mm deux fois par semaine, sans précipitation naturelle. L'application fréquente d'eau à pH 2 durant cette période relativement brève a réduit considérablement l'abondance des Collemboles dans les deux états de décomposition. Dans l'état «le plus avancé» la réduction a été significative même au traitement à pH 3. Chaque espèce de Collembole a montré des réductions d'effectifs. De nombreuses espèces de Mésostigmates semblent atteindre la densité la plus élevée au traitement à pH 4 et pH 3 pour l'état de décomposition «peu avancé» tandis qu'à pH 2 dans l'état de décomposition «avancé» une réduction générale d'abondance a été observée. L'acidification n'a pas influencé l'abondance des Oribates mais la plupart des réactions observées ont été dans le sens de la réduction. Néanmoins, l'abondance a augmenté dans les deux stades de décomposition pour *Tectocepheus velatus* et *Steganacarus* sp. En conséquence, les résultats ont mis en évidence des modèles complexes de réaction avec un effet plus marqué de l'application de pluies acides fréquentes. Les résultats sur le terrain sont en conformité avec d'autres études de terrain et aussi avec un type «d'expérience de choix» tandis que les résultats des expériences en serre ont largement le caractère d'«effets-choc».

Mots clé: **Microarthropodes, Collembola, Acari, acidification, litière de bouleau.**

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